Sand Ripple Generation, Evolution and Decay: An Investigation of Physical and Biological Controls

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LONG-TERM GOALS

The central goal of this research is a deeper understanding of bed state adjustment in mobile sandy sediments on the inner continental shelf, and in particular the adjustment(s) to the combined effects of variable fluid forcing and biological reworking of the sediment surface. The work is motivated by the lack of a suitable observational basis for developing and testing models of the temporal evolution of the seabed roughness spectrum resulting from fluid-sediment-biological interactions in environments subjected to transient wave forcing events.

OBJECTIVES

Our primary objective in this first phase of the project is to quantify the rates of ripple degradation and seabed roughness change arising from biological activity on and within the seafloor. The second objective is to compare the measured degradation rates to those predicted by analytic and numerical models of bed roughness change by biological organisms, as a function of spatial frequency spanning the ripple band.

APPROACH

As part of the SAX04 experiment, two instrumented bottom pods, Dalpod1 and Dalpod2, were deployed at the SAX04 site off Fort Walton Beach, and cabled to the *R/V Seward Johnson*. The bottom pod sensors included single-point velocimeters, an upward-looking acoustic Doppler current profiler (ADCP) with wave measurement capability, downward-looking coherent Doppler profilers, rotary

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14. ABSTRACT

The central goal of this research is a deeper understanding of bed state adjustment in mobile sandy sediments on the inner continental shelf, and in particular the adjustment(s) to the combined effects of variable fluid forcing and biological reworking of the sediment surface. The work is motivated by the lack of a suitable observational basis for developing and testing models of the temporal evolution of the seabed roughness spectrum resulting from fluid-sediment-biological interactions in environments subjected to transient wave forcing events.

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imaging sonars, and laser-video bed profiling systems. This suite of sensors provided measurements of the surface-to-bottom current profile, the wave directional spectrum, bottom boundary layer turbulence and bottom stress, ripple geometry, and the bed roughness spectrum.

In addition to monitoring naturally-occurring changes in bed roughness, SCUBA divers from the Naval Research Laboratory (NRL) carried out manipulative experiments at the pod locations, introducing both artificial ripples (by raking) and colored sediments in specified initial patterns. These manipulative experiments allowed us to observe the time scales of bottom roughness decay as a function of the spatial scale of the initial disturbance, at times when the physical forcing mechanisms were weak.

Finally, we are comparing the above observations of ripple decay to the predictions of biological seabed disturbance models. The primary focus of the modeling component of the project is a numerical automaton bioturbation model, developed for studies of mixing processes in surficial seafloor sediments.

WORK COMPLETED

Routine data collection for our component of SAX04 began on September 30th and, except for intervals when the ship had to leave the mooring because of weather, continued until the final day of the experiment on November 1. The weather events which forced disconnection from the mooring were Tropical Storm Matthew (October 8-11), and a brief unnamed storm on October 14-15. No sensor failures occurred during the experiment and approximately 25 Gbytes of data were acquired, not including the roughly 30 S-VHS tapes of time-lapse video imagery.

Because we did not connect to the mooring until 10 days after the passage of Hurricane Ivan, the ripples which formed during Ivan had already aged considerably. In contrast, we returned to the site immediately after Tropical Storm Mathew, so Mathew's ripples were quite fresh initially. Further, except for the weather event on October 14-15, the physical forcing at the seabed remained relatively weak (see Results below) for the remainder of the experiment. Thus, we were able to monitor the degradation of Mathew's ripples over the 20-day period immediately following the storm event, when physical effects on the ripple field were likely to have been less important than biodegradation.

The video cameras provided the primary documentary information on biological disturbances to the sediment-water interface. Summer student Stephanie Howes has captured all of the video sequences in which organisms were actively reworking the sediment bed. Stephanie has also captured still images of all biological organisms seen by the cameras, and made preliminary species identifications.

Several bed manipulation experiments were carried out by Mike Richardson and the NRL dive team. These included at least two repetitions each of artificial ripples with 3, 4, 6 and 8 cm primary wavelengths, and three experiments with mounds of glass beads. In addition, cores were collected relative to ripple crests and the glass bead mounds, and 5 bulk sediment samples were collected and screened for identification and analysis of infauna. The cores have been split and glass bead counts have been made at 1-cm intervals along the length of the core, and size distributions determined via sieve analysis. This work was carried out by summer student Kathleen Graham. The material screened from the bulk samples has been sorted and preliminary organism identifications made (by graduate student Noreen Kelly), and the sorted material sent to Kevin Briggs at NRL for final identification.

The automaton bioturbation model is being modified for ripple degradation studies by graduate student Dan Reed. Preliminary model runs with subsurface deposit-feeders (i.e. infauna) suggest that 10-cm wavelength ripples persist on time scales of the order of years. Obviously, these results are dependent on the functional groups of organisms in the model, as well as other community and biological parameters. Currently, three functional groups have been implemented: the above-mentioned subsurface deposit-feeders, head-down deposit-feeders, burrow-and-fill mixers (e.g. fiddler crabs). Code for a fourth group (lugworms) is currently being written. Model runs with these groups will be carried out during the coming year, for ripples of different scale. Based upon the SAX04 observations, fish-induced disturbance of the seabed will also need to be incorporated into the model.

A major focus during the 10 months since SAX04 has been on the evolution of the seafloor roughness subsequent to TS Mathew. All of the data from this period have undergone primary quality control, and near-final data products generated for most, including: ADV-type current meters, the Waves-ADCP, the rotary sonars, the coherent Doppler profilers, and the laser-video imagery. In the latter case, the video footage of the laser-illuminated bed sequences has been captured to disk (by Kathleen Graham), and the extraction of the (uncalibrated) raw bed profiles completed.

RESULTS

The spatial structure of the ripples generated by TS Mathew is illustrated by the acoustic fanbeam image in Figure 1a. Ripple wavelengths were about 50 cm. The high contrast between dark and light areas indicates that the ripples were sharp-crested. More than 14 days later, and roughly 16 days following the Mathew event, these features were much less distinct (Figure 1b). Note in particular the narrower and less distinct shadows in the troughs, indicating a significant reduction in ripple height. Figure 2 shows the time evolution of the bed elevation spectrum over the full 19-day period following Mathew, including the period spanned by the 2 images in Figure 1. The gap in the record is due to the vessel leaving the mooring on October 14-15 (Yeardays 289-290). A gradual decrease in the peak spectral density at 2 cpm is evident in the first 15 days, as is the loss of energy at the first harmonic, 4 cpm, in the early part of the record. The rapid disappearance of 1st harmonic energy is consistent with the ripples becoming less sharp-crested with time. Significantly, the variance in the spectral band above 4 cpm (not shown) did not change significantly during this 19-day interval.

The results in Figures 1 and 2 illustrate the observed rates of ripple degradation at this site for a period in which, as previously mentioned, physical mechanisms sufficiently energetic to influence the local sediment dynamics were relatively weak. The implication is that the observed rates of decay were largely the result of biological activity, an implication which is supported by the video imagery, and which provides the basis for the comparisons with the automaton and diffusive models which are in progress. A necessary component of our SAX04 study has been to quantify the physical forcing conditions in the bottom boundary layer: just how weak was “weak”? The CDP-measured velocity profiles in the 10-cm thick layer immediately above the bottom have been used to provide two independent estimates of the turbulent kinetic energy dissipation rate near the bed. One estimate, ε_s, is based on the energy spectrum of the turbulence the inertial subrange; the second, ε_g, on the time series of the mean-square vertical turbulent velocity gradient. As shown in Figure 3, the two methods yield results that are gratifyingly similar: that is, they are proportional, and the same order of magnitude. Furthermore, while a noise floor has been removed from the energy spectrum in computing the inertial dissipation rates, the gradient method estimates include the noise. Figure 3 indicates that

the noise level for ε_g is about 0.015 cm^2/s^3 which, if subtracted from the ε_g values in the Figure, would bring the gradient and inertial subrange estimates into nearly 1:1 agreement. Thus, a typical dissipation rate during this period was O(0.01) cm^2/s^3. This value corresponds to $u_* \approx 0.5$ cm/s assuming a 10-cm length scale for the largest eddies in the wave bottom boundary layer, yielding a Shields parameter of about 0.004 for the 350-μm median diameter sand at the site. The 0.004 value is well below the 0.05 critical value of the Shields parameter at the threshold of grain motion, thus providing a measure of how "weak" the physical forcing at the seabed was for this period during SAX04.

While the forcing was weak, it was not negligible. At the end of the record in Figure 2, the bed elevation spectra exhibit an increase in the bed roughness variance at all spatial frequencies across the ripple band. While this ripple growth (and re-organization) was associated with a forcing event that developed over this time period and continued for 1 or 2 days afterward, the nearbed wave orbital velocities (Figure 4) and currents (not shown) exhibit only modest increases, and did not in fact reach levels as high as had occurred 10 days earlier. Thus, it seems likely that a combination of biological and physical mechanisms will be required to provide a full explanation of the results in Figure 2.

IMPACT/APPLICATIONS

This project is directly relevant to questions related to sound scattering from and penetration into sandy marine sediments, and to the arguably broader question of the predictability of ripple geometry on the inner continental shelf. Both questions arise in relation to buried object detection, in relation to the rates of burial or exposure of objects on the seafloor, in relation to temporal and spatial variability in seafloor acoustic scattering, and in relation to predicting the physical conditions (wave heights, currents, etc.) on the inner shelf area at a given time: all "needs-to-know" for naval operations in coastal environments.

PUBLICATIONS

Hay, A. E. and T. Mudge, 2005. Principal bed states during SandyDuck97: Occurrence, spectral anisotropy, and the bed state storm cycle, *J. Geophys. Res.*, **110**, C03013, doi: 10.1029/2004JC002451.

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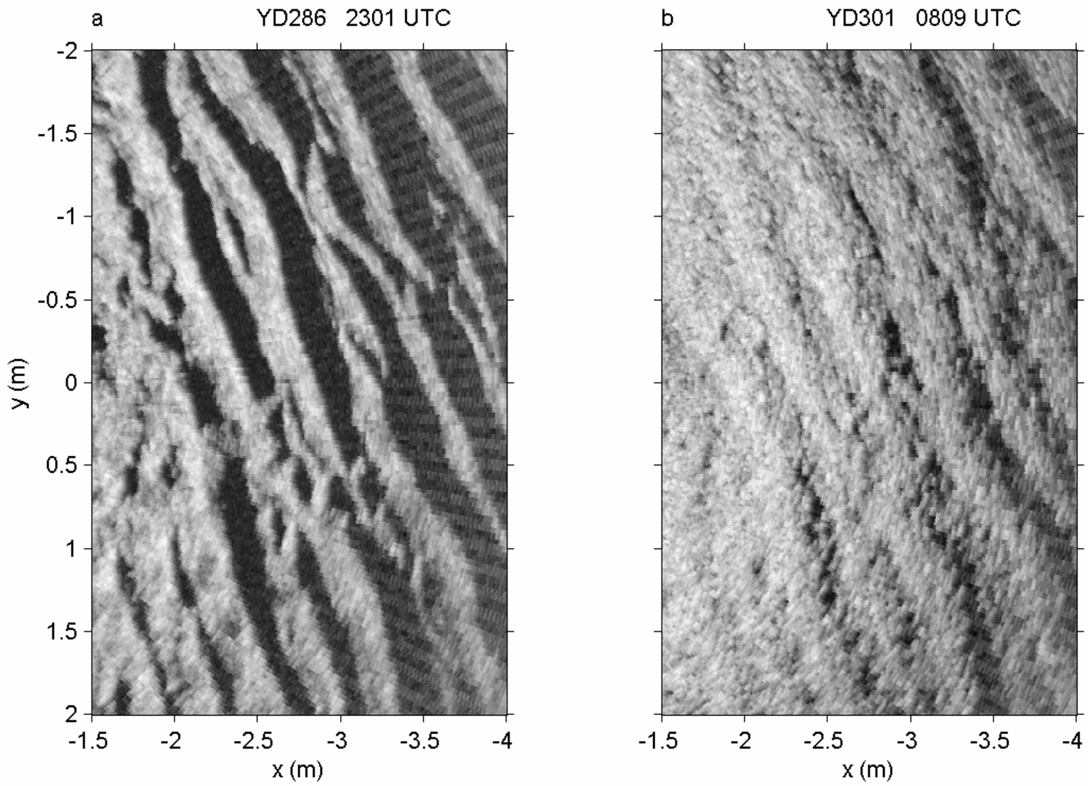

Figure 1: Two acoustic images of the seabed at Dalpod 1: (a) 1 d after Tropical Storm Mathew and (b) about 14.3 d later. The images were acquired with a 2.25 MHz rotary sonar centered at the xy coordinate origin: i.e. 1.5 m to the left of each image. Ripple troughs are thus more in the acoustic shadows (darker shades of grey) of the ripple crests with increasing distance to the right. Note the 0.5-m wavelength ripples prominent in (a), and highly degraded in (b).

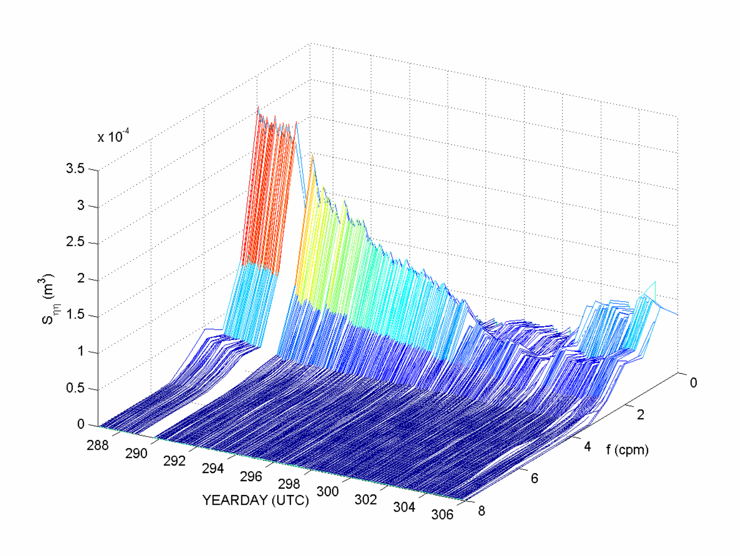

Figure 2: Bed elevation spectra for the 19-d period following Tropical Storm Mathew, from 2.25 MHz rotary sonar profiles of the seabed at Dalpod 1. Note the gradual decay of the primary ripple peak at 2 cpm (50-cm wavelength).

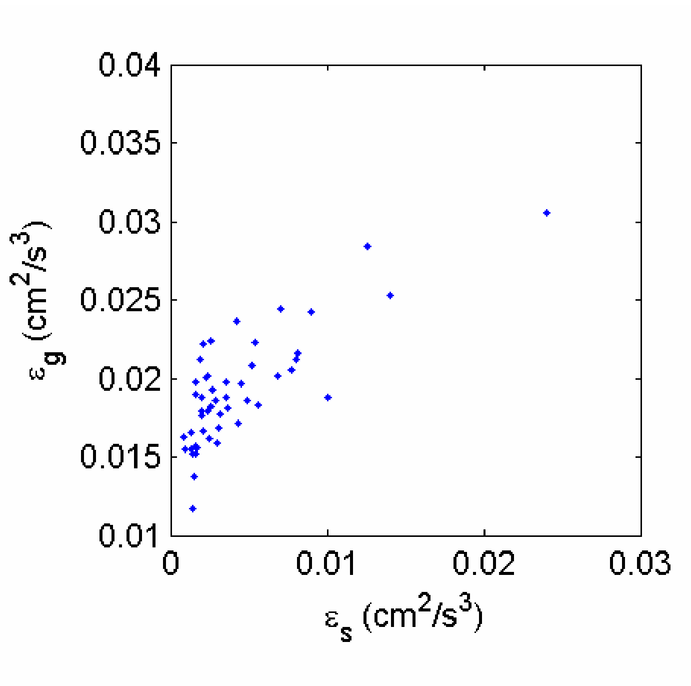

Figure 3. Turbulent kinetic energy dissipation rates in the 10-cm immediately above bottom: ε_g was estimated using from the kinetic energy spectrum in the inertial subrange; ε_g from the gradient of the vertical velocity fluctuations.

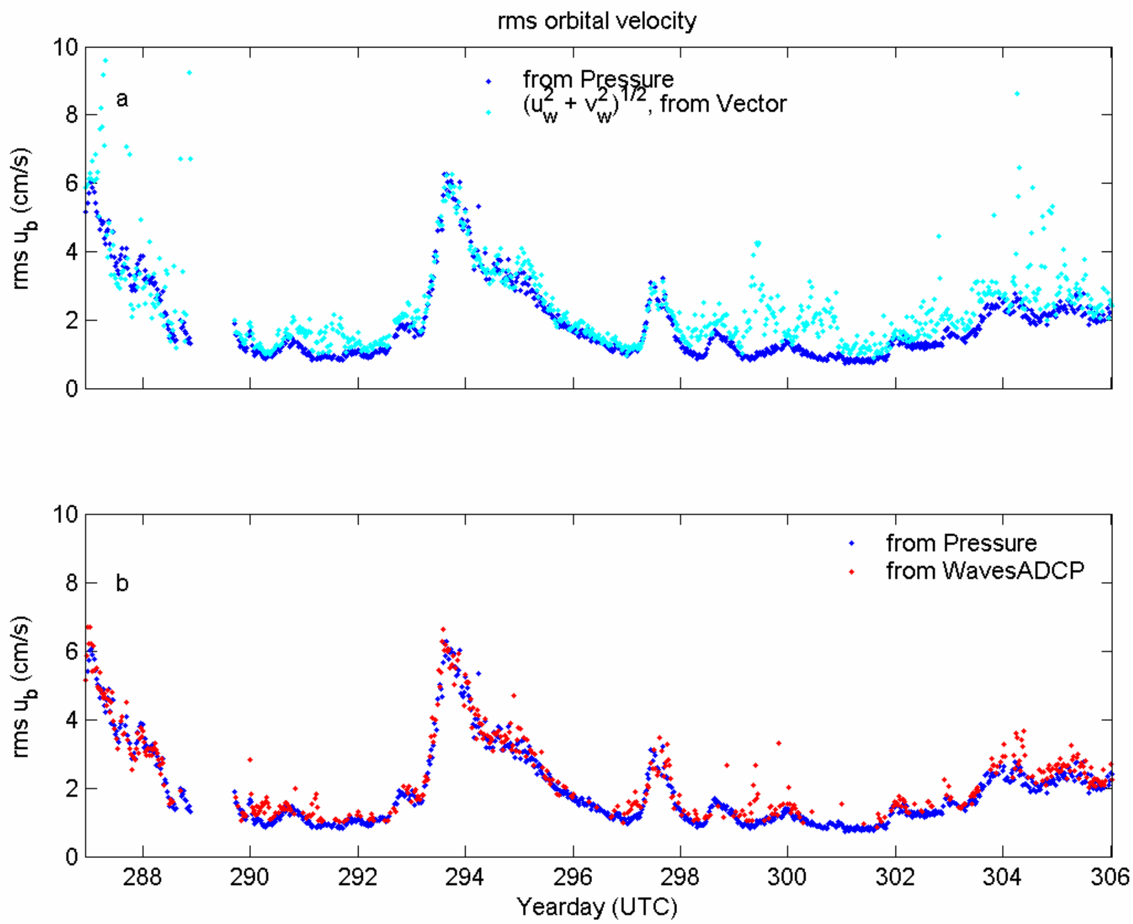

Figure 4. Near-bed wave orbital velocity amplitudes (rms) determined: directly from the Nortek Vector velocity measurements (a: cyan dots); from the pressure data assuming linear wave theory (a and b: blue dots); and from the WavesADCP surface wave orbital velocities, also converted to nearbed values assuming linear wave theory(b: red dots).